

# **The MULiple SCattering in Lidar Experiments (MUSCLE) Intercomparison Exercises, *and* *Other I3RC Considerations***

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# Topics

- **MUSCLE**
  - what is it?
  - intercomparisons
- **Intercomparison overview**
  - with a gap to fill?
- **3D RT: Focus on the big-picture**
  - where we are, and
  - where to go

# MUSCLE

- **Origins - 1995, ending with ...**
  - Lidar-In-space Technology Experiment (LITE) on Space Shuttle in Fall 1994, esp. night orbit #135
  - Applied Optics B Special Issue (5+1 papers)
- **1996 - 2005 period:**
  - Quebec City
  - Jerusalem
  - Florence
  - Williamsburg
  - Oberpfaffenhoffen (near München)
  - St. Petersburg
  - Quebec City
- **Next?**

## **Applied Physics B: Lasers and Optics, Volume 60, Issue 4, April 1995**

Bruscaglioni, P.; Ismaelli, A.; Zaccanti, G.,  
**Monte-Carlo calculations of LIDAR returns: Procedure and results,**  
Applied Physics B: Lasers and Optics,  
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Flesia, C.; Schwendimann, P.,  
**Analytical multiple-scattering extension of the Mie theory: The LIDAR equation,**  
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Starkov, A.V.; Noormohammadian, M.; Oppel, U.G.,  
**Stochastic model and a variance-reduction Monte-Carlo method for the calculation of light transport,**  
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Winker, D.M.; Poole, L.R.,  
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Volume 60, Issue 4, April 1995, Pages 341-344.

Zege, E.P.; Katsev, I.L.; Polonsky, I.N.,  
**Analytical solution to LIDAR return signals from clouds with regard to multiple scattering,**  
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Bissonnette, L.R.; Bruscaglioni, P.; Ismaelli, A.; Zaccanti, G.; Cohen, A.;  
Benayahu, Y.; Kleiman, M.; Egert, S.; Flesia, C.; Schwendimann, P.; et al.,  
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# **MUSCLE Comparison Plots**

# **3D RT Comparisons, Compared**

- I3RC (deterministic, computational)
- ICRCMM - III (statistical, modeling)
- RAMI (vegetation canopies)
- MUSCLE (localized/pulsed sources)

# 3D RT Comparisons, Compared

- I3RC (deterministic, computational) pixels
- ICRCM - III (statistical, modeling) spectra
- RAMI (vegetation canopies) BRDFs
- MUSCLE (localized/pulsed sources) time/  
range

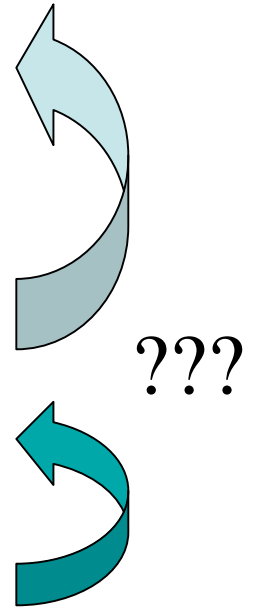


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- ***Non-vegetated surfaces?***
  - DIRSIG (Rochester)
  - McSCENE (Spectral Sciences, Inc.)
  - Something with radiosity
  - Etc.

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**Focus on the Big  
3D RT Picture**

# 3D RT Problem Classification

$I(\mathbf{x}, \vec{\Omega})$	<b>Diagnostics</b> use radiances [sample $\Omega$ ]	<b>Energetics</b> use fluxes [sum over $\Omega$ ]
“pixel” scales: structure <u>resolved</u> [sample $x$ ]		
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“pixel” scales: structure <u>resolved</u> [sample $x$ ]	Adjacency problems <div>2D</div>	3D radiative heating/cooling rates in CRMs
“domain” scales: structure <u>unresolved</u> [sum over $x$ ]	Large-footprint problems	GCM radiation parameterization problem <div>1D</div>

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“domain” scales: structure <u>unresolved</u> [sum over $x$ ]	Large-footprint problems <div>0D</div>	GCM radiation parameterization problem <div>1D</div>



# Atmospheric 3D RT Evolution


1975 - 1995 (and beyond):

3D damage *assessment* for 1D RT modeling  
i.e., uncertainty quantification

Since 1995:

- damage *mitigation* (back to 1D, w/o bias)
- *innovation* (exploit 3D RT phenomena)

# 3D Damage Mitigation

- Effective optical depth (e.g., Cahalan 1994)
  - Gamma-Weighted 2-Stream (Barker 1996)
  - Rescaled optical properties (Cairns et al. 2000)
  - Effective optical properties (Szczap et al.  $\approx$ 2002)
  - Nonlocal Independent Pixel Approximation - NIPA (Marshak et al. 1998)
  - Etc.
- 

# Innovation

- In energetics, this calls for **new equations** to solve:
  - Markovian stochastic media;
  - Stephens' (1998b) closure scheme;
  - Power-law propagation kernels, formerly known as Lévy/anomalous photon diffusion model.
- In diagnostics, this means going beyond improved or adapted sampling of photon state-space (wavelength, position/direction, maybe polarization). Uses **3D photon flow patterns** and/or population properties.

# Innovation, continued:

## *Examples in Remote Sensing*

- Exploitation of radiative smoothing in  $R$  or in  $T$
- Normalized Difference Cloud Index - NDCI
- “Bright/Dark” radiance ratio technique for dense compact clouds
- Pathlength moments from O<sub>2</sub> A-band spectroscopy at fine or ultra-fine resolution
- Large-footprint cloud lidar
  - LITE
  - “in situ” cloud lidar (not “remote” per say)
- Off-beam cloud lidar w/ space- and time-resolution
  - WAIL (at LANL) & THOR (at NASA-Goddard)

# “Take Home” Messages

- **Verification and Validation (V&V)**
  - “solve the equations *right*”  
(Roache  $\approx$ 2000)
  - “solve the *right* equations”
- **Work with others ...**
  - Atmosphere - Ocean - Land - Planetary
    - Modelers
    - Observers
  - Need more/better approximation techniques
  - Outreach & teaching
- **Dream up new observations**
  - New synergies
  - New instruments